INTERFEROMETRIC MEASURING DEVICE

5   Field of the Invention

The present invention relates to an interferometric measuring device for recording the shape, the roughness or the distance to the surface of a measured object, using a modulation interferometer to which short-coherent radiation is supplied,

10   and a measuring probe that is spatially separated from the modulation interferometer and is coupled or able to be coupled to the latter via an optical fiber device.

Background Information

In an interferometric measuring device described in published

15   German patent document DE 100 57 539, the interferometric measuring device is subdivided, on the one hand, into a modulation interferometer and, on the other hand, into a measuring probe having an additional interferometer unit. In the measuring probe there is provided a probe-optical fiber

20   unit having an exit surface at the object end which, for instance, may be beveled. By the way, such an interferometric measuring device works in a manner described in greater detail in published German Patent document DE 198 19 762.

In an additional interferometric measuring device described in

25   published German patent document DE 198 19 762, one part, the so-called modulation interferometer, is spatially separated from the actual measuring probe, and is optically connected to it via a light-conducting fiber system, so that the measuring probe may be designed as a relatively simply constructed,

30   easily manipulable unit. A broad-band, short-coherent

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radiation is supplied to the modulation interferometer, which
is split into two beam components at the input of the
modulation interferometer with the aid of a beam splitter, of
which the one is shifted in its light phase or light frequency
5   with respect to the other, using a modulation device, such as
an acousto-optic modulator. In the modulation interferometer,
one of the two beam components runs through a delay element
which generates an optical path difference of the two beam
components which is greater than the coherence length of the
10   short-coherent radiation. In the measuring probe, in a
measuring arm, with respect to a reference arm, an additional
optical path difference is generated in such a way that the
path difference effected by the delay element is compensated
for, and, consequently, an interference is created between the
15   reference radiation coming from the reference plane of the
reference arm and the radiation coming back from the object
surface in the measuring arm, which interference is
subsequently analyzed so as to ascertain the desired surface
property (shape, roughness, clearance distance) via a phase
20   evaluation. In the measuring probe, the measuring arm and the
reference arm are situated in one exemplary embodiment in one
common light path (common path), a partially transmitting
optical element being provided for forming the measuring arm
and the reference arm.

25   A similar interferometric measuring device having such a
modulation interferometer and a measuring probe connected to
it via a light-conducting fiber system is also described in
published German patent document DE 198 08 273. In a beam
splitting and radiation detecting unit, using a receiving
30   equipment, the radiation brought to interference is split into
radiation components of different wavelength, so as to form
therefrom a synthetic wavelength and to increase the measuring
range.

In the interferometric measuring devices named above, which
are based on heterodyne interferometry, but which utilize the
properties of a broad-band, short-coherent radiation, the
modulation interferometer, designed as a Mach-Zehnder
5   interferometer, has a system of classical optical components,
such as collimation optics lying upstream of the input end of
the beam splitter, with the beam splitter and reflecting
mirror at the input end and the output end, respectively. In
this context, the beam components experience several
10   reflections at the beam splitter surfaces and at the mirrors,
before they are coupled into the optical light-conducting
fiber system. The optical components have to be positioned
with great accuracy, since the effect of every angle error is
doubled by the reflection. In this context, it is difficult to
15   ensure the durability of a calibration. In connection with
fitting in a glass plate to compensate for optical
asymmetries, additional difficulties come about during the
calibration. A costly construction is connected with these
difficulties, an exact adjustment to the properties of the
20   measuring probe being also required.

An object of the present invention is making available an
interferometric measuring device which permits achieving as
accurate as possible a measurement, using a simplified
construction.

25   Summary

According to the present invention, it is provided that the
angle of inclination of the exit surface of the probe-optical
fiber unit with respect to the normal of the optical probe
axis is at least 46^0.

30   Using this design of the exit surface, one achieves an
optimal coupling behavior in the case of right-angled beam
deflection in this transitional region of the measuring beam

guided to the surface of the measured object and returning from it, whereby the accuracy of the measurement is substantially favored, especially in inaccessible, tight hollow spaces.

5   An additional improvement may be achieved by making the angle of inclination at least 48^0.

Furthermore, interferences are suppressed by providing a jacket-like covering of an object-end section of the probe optical fiber unit with an anti-reflection treatment.

10 Additional improvement to the coupling of the radiation may be achieved by providing the exit surface with a reflection treatment.

An example embodiment of the present invention is advantageous in that a partially transmitting region between a probe fiber

15 and a fiber section of the measuring probe is formed with the aid of an exit surface of a probe fiber that is slanted at an exit angle with respect to the optical probe axis, and with the aid of an entrance surface of a fiber section following on the object end that is also slanted at an exit angle with

20 respect to the optical probe axis. Furthermore, a wedge-shaped gap is formed between the exit surface and the entrance surface, and the exit surface and the entrance surface are inclined in the same direction with respect to the probe axis.

In this regard, it is advantageous that the exit angle and the

25 entrance angle are selected so that a Fresnel reflection is effected. The radiation transmission for reliable measuring results is favored by the exit angle α being between 5^0 and 8^0, and the entrance angle being between α and 0^0.

An additional advantageous example embodiment provides that

30 the probe fiber and the fiber section are accommodated axially

aligned in a tubule-shaped accommodation, which is surrounded
by an outer tube of the measuring probe. On the end face of
the accommodation, that faces away from the measured object, a
positioning element is provided that surrounds the probe fiber

5   and is also accommodated concentrically to the tube, and the
fiber section is fixed in the object-end, front part of the
accommodation, and the probe fiber is fixed in the rear part
of the accommodation that is distant from the object, and/or
in the tube.

10   Furthermore, one favorable example embodiment is achieved in
that the front part of the accommodation is separated from the
rear part of the accommodation by diametrically opposite gaps,
one gap being limited at the rear in the elongation of the
slanted exit surface of the probe fiber, and the other gap

15   being limited on the front in the elongation of the slanting
entrance surface. In addition, the front part and the rear
part of the receptacle are enclosed by a common sleeve-shaped
retaining ring, which is surrounded on the outside by the
tube, and that a front section of the fiber section has a

20   smaller diameter compared to its rear section.

Another example embodiment provides that the modulation
interferometer has at least partially a polarization-
maintaining, light-conducting structure in the form of an
optical fiber conductor or integrated optics, the light-

25   conducting structure being interrupted at at least one arm.

Brief Description of the Drawings

Figure 1 shows a schematic representation of an overall
construction of an interferometric measuring device having a
modulation interferometer and a measuring probe.

30   Figure 2 shows a more detailed illustration of an example
embodiment of the modulation interferometer shown in Figure 1.

Figure 3 shows a side view of the measuring probe and the measured object with a representation of the radiation error in offset.

Figure 4 shows a schematic side-view representation of a fiber part of the measuring probe.

Figure 5 shows a schematic illustration of the front section of the measuring probe.

Figure 6 shows a schematic illustration of a further example embodiment of the front section of the measuring probe.

Detailed Description

As shown in Figure 1, the interferometric measuring device using the principle of heterodyne interferometry has a broad-band, short-coherent light source 1, whose radiation is supplied to a so-called modulation interferometer 2. In modulation interferometer 2, which is shown in greater detail in Figure 2, radiation $s(t)$ is split at a first beam splitter 2.3 into a first beam component 2.1 guided via a first arm, having a partial radiation $s_1(t)$, and a second beam component 2.1' guided via a second arm, having a partial radiation $s_2(t)$. The two beam components are recombined at the exit side at an additional beam splitter 2.10, and from there the recombined beam is conducted via a light-conducting fiber device 6 to a distant measuring probe 3. From measuring probe 3, which is constructed, for example, as a Fizeau interferometer or a Mirau interferometer, the radiation subsequently reaches, via an additional light-conducting fiber device 7, a receiver device 4 having a beam splitting unit 4.1 and downstream photoelectric receivers 4.2, in which a conversion into electrical signals takes place. In a downstream evaluation unit 5, having a phase detector 5.1 and a computing unit 5.2, the properties of the measuring surface picked up using

measuring probe 3 (such as roughness, shape, clearance distance) are then ascertained.

Modulation interferometer 2 is designed as a Mach-Zehnder interferometer, the two arms in connection to first beam splitter 2.3 having first and second entrance-side light-conducting fibers 2.11, 2.11', and first and second exit-side light-conducting fibers 2.12, 2.12', which lead to additional beam splitter 2.10. First beam splitter 2.3 is, in this case, formed in an optical fiber, by which the radiation coming from light source 1 is advanced. At the exit of the coupler thus formed, the beam components are collimated with the aid of lens-type coupling elements 2.4, 2.4', and the two collimated beam components pass through a first or a second modulating unit 2.2, 2.2' in the form of, e.g., an acoustooptical modulator, a fiber optic piezo modulator or a thermal phase modulator, the modulating units 2.2, 2.2' being advantageously able to be developed also as integrated optical components. In order to correct the chromatic dispersion, at least one of beam components 2.1, 2.1' passes through a glass plate which is situated in a first or a second light path. The choice of the positioning of the glass plate and/or its thickness is determined by calculation. In their further course, first beam component 2.1 and second beam component 2.1' are conducted to a first or a second lens-type light guide element 2.6, 2.6' and coupled into the first or the second exit-side light-conducting fiber 2.12, 2.12'. First and second exit-side light-conducting fiber 2.12, 2.12' have different optical path lengths, to the extent that the optical path difference $\Delta L = L_2 - L_1$ between the two arms is greater than the coherence length of the short-coherent radiation s(t). One of the lens-type coupling elements 2.4, 2.4' or light-conducting elements 2.6, 2.6', for example, light-conducting element 2.6', may be fastened to a

calibrating device, using which the optical path difference ΔL may be adjusted, by hand or with the aid of a motor, for instance, while using a micrometer bench, in such a way that the path difference ΔL between the two arms is tuned to that

5   of measuring probe 3 so as to effect interference using measuring probe 3. Light-conducting fibers 2.11, 2.11', 2.12, 2.12' used are monomode. Besides, they may be apolarization-receiving, especially if light source 1 is polarized and/or if modulating units 2.2, 2.2' are formed of double-refractive

10   crystals and/or if installation at the coupling locations does not yield satisfactory stability with respect to the polarization direction in the two interferometer arms. To achieve the optical path difference, an optical alternate route (delay line) 2.9' is provided, for example, in second

15   exit-side light-conducting fiber 2.12'.

Probe 3, which is used to detect the object surface, which probe is designed, for instance, as a Fizeau interferometer or a Mirau interferometer, has a reference branch having a reference plane and a measuring branch leading to the object

20   surface, optical path differences of which two branches are selected so that the path difference generated in modulating interferometer 2 is compensated for, so that the measuring beam coming from the object surface and the reference beam coming from the reference plane interfere when they are

25   superposed. The interfering radiation is supplied to beam splitting unit 4.1 for spectral partitioning into components of different wavelengths, and the split components are subsequently supplied to the allocated photoelectric receivers 4.2. The desired surface property is ascertained from the

30   interfering radiation and the electrical signals obtained from it by evaluating the phase differences, by using phase detector 5.1 and subsequent computing unit 5.2. In this context, the evaluated phase difference is created by the

frequency difference, generated by first or second modulating unit 2.2, 2.2', which, corresponding to the heterodyne method, is relatively low with respect to the fundamental frequency. The calculation is carried out according to the formula:

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$$\Delta\varphi = 2\pi \cdot \left(2e / \Lambda\right) + \varphi_0$$

where

φ_0 is a constant,

$\Lambda = \lambda_1 \cdot \lambda_2 / (\lambda_2 - \lambda_1)$ is the synthetic wavelength of the measuring device,

10 λ_1 is the wavelength at a first photoelectric receiver,

λ_2 is the wavelength at a second photoelectric receiver,

e is the measuring distance.

From this, using evaluation unit 5, the respective recorded clearance distance of the surface at a measuring point is

15 determined from the relationship:

$$e = \Delta\varphi \cdot \left(2\pi\right) \cdot \left(\Lambda/2\right)$$

Distance measure e is thus determined from a measurement of the phase between two electrical signals, and therefore the measurement is independent of the optical intensity received

20 by the photodiodes.

Figure 3 shows a fiber part of the measuring probe, e.g., designed as a Mirau interferometer, having a monomode light-conducting fiber, and the path displacement of the incident radiation $s_2(t)$ and $s_1(t)$, as well as the retracing radiation

25 components $r_1'(t)$, $r_1(t)$, $r_2(t)$ and $r_2'(t)$ from the surface of measuring object 8 and a partially transmitting region 3.3 between an object-side exit surface 3.31 (see Fig. 4) of a probe fiber 3.1 and an entrance surface 3.32 (see Fig. 4), farther away from the object, of a fiber section 3.2. The

retracing portions of radiation $r_1'(t)$ and $r_1(t)$ come about, in
this context, from the radiation $s_1(t)$ which has passed through
the arm of modulating interferometer 2 without the alternate
route, portion of radiation $r_1'(t)$ being reflected by partially

5   transmitting region 3.3 and portion of radiation $r_1(t)$ being
reflected by the surface of measured object 8. By contrast,
the retracing portions of radiation $r_2(t)$ and $r_2'(t)$ come about
from the radiation $s_2(t)$ of modulating interferometer 2 which
has passed through the optical alternate route, retracing

10   portion of radiation $r_2(t)$ having been reflected by partially
transmitting region 3.3 and retracing portion of radiation
$r_2'(t)$ having been reflected by the surface of measured object
8. It is shown that, corresponding to the compensation of the
path difference ΔL formed in modulating interferometer 2 by

15   measuring probe 3, only the retracing portions of radiation
$r_1(t)$ and $r_2(t)$ lie within the coherence length and interfere
with each other.

In the exemplary embodiment shown in Figure 3, object-side
exit surface 3.4 of fiber section 3.2 is inclined at an angle

20   of 45^0 with respect to optical probe axis 3.5. A reflective
metallic or dielectric coating is applied to exit surface
3.4. The radiation is bent in this manner essentially at a
right angle and guided to the surrounding surface of the
object, and the radiation reflected by the surface reenters

25   the light-conducting fiber via exit surface 3.4.

As shown in Figures 4 to 6, partially transmitting region 3.3
is formed between exit surface 3.31 of probe fiber 3.1 and
entrance surface 3.32 of fiber section 3.2 by an inclination
of exit surface 3.31 at an angle α with respect to the normal

30   of probe axis 3.5, and by an inclination of entrance surface
3.32 of fiber section 3.2 at an angle β with respect to the
normal of probe axis 3.5, the angle α being greater than the

angle β, and a wedge-shaped gap formed between the exit
surface 3.31 and the entrance surface 3.32. The alignment of
the inclination with respect to the normal is oriented in the
same manner towards the object in the case of exit surface

5   3.31 and entrance surface 3.32. Angle α of exit surface 3.31
is selected so that the radiation flow of the Fresnel
reflection on exit surface 3.31 is not guided by probe fiber
3.1. For a monomode light-conducting fiber having a numerical
aperture of 0.12, the angle α is advantageously about 6^0.

10   Angle β is selected so that the radiation flow of the Fresnel
reflection is guided onto entrance surface 3.32 of fiber
section 3.2 by probe fiber 3.1, the extent of the radiation
flow that is to be coupled into probe fiber 3.1 being taken
into consideration. If angle β is equal to 0^0, the coupling

15   rate amounts to about 3.6 %. If angle β runs counter to angle
α, the degree of coupling tends toward 0. If angle β tends
counter to angle α, the transmission for this transition and
a retracing radiation goes toward 86 %. If, however, angle β
is equal to 0^0, the transmission amounts to about 60 %. A

20   numerical aperture of 0.12 results, for example, at a
wavelength of 1.550 nm and a diameter of 10.4 μm. Angle α
should not be selected to be less than about 5^0.

The reflection treatment of exit surface 3.4 of fiber section
3.2 may be reduced or avoided if exit angle γ (see Fig. 4) is

25   increased so as to achieve total reflection at exit surface of
7. This is the case, for instance, in the case of a monomode
light-conducting fiber having a numerical aperture of 0.12, at
an exit angle γ that is above 48^0.

At the object-side end region of fiber section 3.2, an anti-

30   reflection treatment 3.22 may be provided on the outer surface
(cladding), in order to reduce the sensitivity with respect to
the Fresnel reflection, or exit angle γ may be enlarged to the

extent that the radiation flow of this reflection is no longer coupled into fiber section 3.2.

As shown in Figure 5, probe fiber 3.1 and fiber section 3.2 may be accommodated in the same tubule-type accommodation 3.6 and brought into contact. Accommodation 3.6 is the same that is used for connectors of monomode light-conducting fibers. Accommodation 3.6 is inserted into a tube 3.9 of the measuring probe 3 that surrounds it. On the inside of tube 3.9, on the end face of accommodation 3.6 lying away from the object, there is subsequently also a positioning piece 3.7 for guiding and preadjusting probe fiber 3.1. Fiber section 3.2 is fixed on the inside of the accommodation with the aid of adhesives 3.8', while probe fiber 3.1 is fixed in accommodation 3.6 and/or positioning piece 3.7 with the aid of adhesives 3.8.

Another procedure for aligning and fixing probe fiber 3.1 and fiber section 3.2 in probe 3 is shown in Figure 6. Probe fiber 3.1 is introduced into a rear section 3.6' of tubule-type accommodation 3.6, and the front end face of rear section 3.6' and of exit surface 3.31 of probe fiber 3.1 are polished at the desired angle, the front end face in the region of the front-most edge of probe fiber 3.1 being aligned normal to optical axis 3.5 of probe fiber 3.1. Accordingly, the rear end face of a front section 3.6" of accommodation 3.6 is polished corresponding to the desired entrance surface 3.32 of fiber section 3.2, the region of the rear end face of front section 3.6" of accommodation 3.6, which is adjacent to the hindmost edge of fiber section 3.2, being aligned normal to optical axis 3.5 of probe fiber 3.1. Between rear section 3.6' and front section 3.6" of accommodation 3.6 there comes about, in this context, the set-up shown in Figure 6 in longitudinal section. The two sections 3.6' and 3.6" of accommodation 3.6 are axially

aligned with each other using a retaining ring 3.10 that is applied, for example slotted, and inserted into tube 3.9. Furthermore, in tube 3.9 there is also inserted, in turn, bordering on the rear end face of accommodation 3.6, a

5 concentric positioning piece 3.7 for calibrating and prefixing probe fiber 3.1, as in the exemplary embodiment according to Figure 5. The fixing of probe fiber 3.1 and of fiber section 3.2 using adhesives 3.8, 3.8' thus also takes place corresponding to the exemplary embodiment according to

10 Figure 5, fiber section 3.6 being fixed in front section 3.6" of accommodation 3.6.

It is also possible to align sections 3.6' and 3.6" by inserting them into a V-shaped profile. Because the two sections 3.6', 3.6" of accommodation 3.6 are inserted

15 separately, the outermost end of measuring probe 3 may be changed immovably and corresponding to the characteristic of the measured object, the same probe fiber 3.1 being retained.

As Figures 4 to 6 also show, the outer section of fiber section 3.2 is reduced in its diameter, so that it may also

20 be introduced into tight holes of a measured object 8, whose diameter amounts to less than 130 µm, for example. The diameter of a monomode light-conducting fiber having outer treatment (cladding) usually amounts to 125 µm. The diameter may be reduced with the aid of chemical treatment using an

25 appropriate acid or of heat treatment, so as to obtain a desired tapering 3.21. Antireflecting treatment 3.22 is then undertaken in the region of the section of lower diameter. These measures, too, contribute to ability to undertake reliable measurements even in tight recesses of a measured

30 object 8.